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ANTENNA LABORATORY

Technical Report No. 22

**EXPERIMENTAL INVESTIGATION  
OF THE  
CONICAL SPIRAL ANTENNA**

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Contract No. AF33(616)-3220  
Project No. 6(7-4620) Task 40572  
WRIGHT AIR DEVELOPMENT CENTER



ELECTRICAL ENGINEERING RESEARCH LABORATORY  
ENGINEERING EXPERIMENT STATION  
UNIVERSITY OF ILLINOIS  
URBANA, ILLINOIS

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Antenna Laboratory

Technical Report No. 22

EXPERIMENTAL INVESTIGATION  
of  
THE CONICAL SPIRAL ANTENNA

by

R. L. Carrel

25 May 1957

Contract AF33(616)-3220  
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Electrical Engineering Research Laboratory  
Engineering Experiment Station  
University of Illinois  
Urbana, Illinois

## ABSTRACT

This paper presents the results of an experimental investigation of the conical spiral antenna. The design of this antenna was based on frequency independent antenna concepts. Consequently, most of the emphasis was placed on recording the radiation pattern for various changes in the design parameters. The pattern was found to remain constant over a wide band, aside from a rotation which was predicted by the theory. However, the "quality" of the patterns was rather poor, and no combination of design parameters was found which would correct this feature.

In addition, measurements of the input impedance are presented. Several measurements of the current amplitude distribution were made.

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# THE CONICAL SPIRAL ANTENNA

## 1. INTRODUCTION

The conical spiral antenna consists of the projection of a single planar equiangular (logarithmic) spiral onto the surface of a cone, as shown in Fig. 1. It has been demonstrated that such a structure, i.e., a structure which is defined completely in terms of angles, should exhibit characteristics which are independent of frequency.<sup>1</sup>

The conical spiral has naturally evolved from the planar equiangular spiral, whose unusual properties have been investigated and reported by J.D. Dyson of the University of Illinois.<sup>2,3,4</sup> Almost from the beginning of the above investigation, the need for a cavity behind the planar spiral if the planar spiral was to have more than limited utility became evident. This is because the planar spiral radiates in both hemispheres. Cylindrical, cone-shaped, and inverted cone-shaped cavities were placed behind one side of the planar spiral. In every case the addition of the cavity severely degraded the radiation characteristics.

## 2. EXPERIMENTAL RESULTS

### 2.1 The Expanded Spiral

The next step seemed to be to expand a single spiral in a cone shape, and feed it from a coaxial line over a ground plane, as shown in Fig. 2. After one model was designed, it was found that the difficulties encountered in the fabrication were such that the design could not be held to any degree of precision.

### 2.2 The Conical Spiral

The above difficulties led to the conception of the spiral developed on a cone, as shown in Fig. 1. This antenna also has the advantage that it can be fed



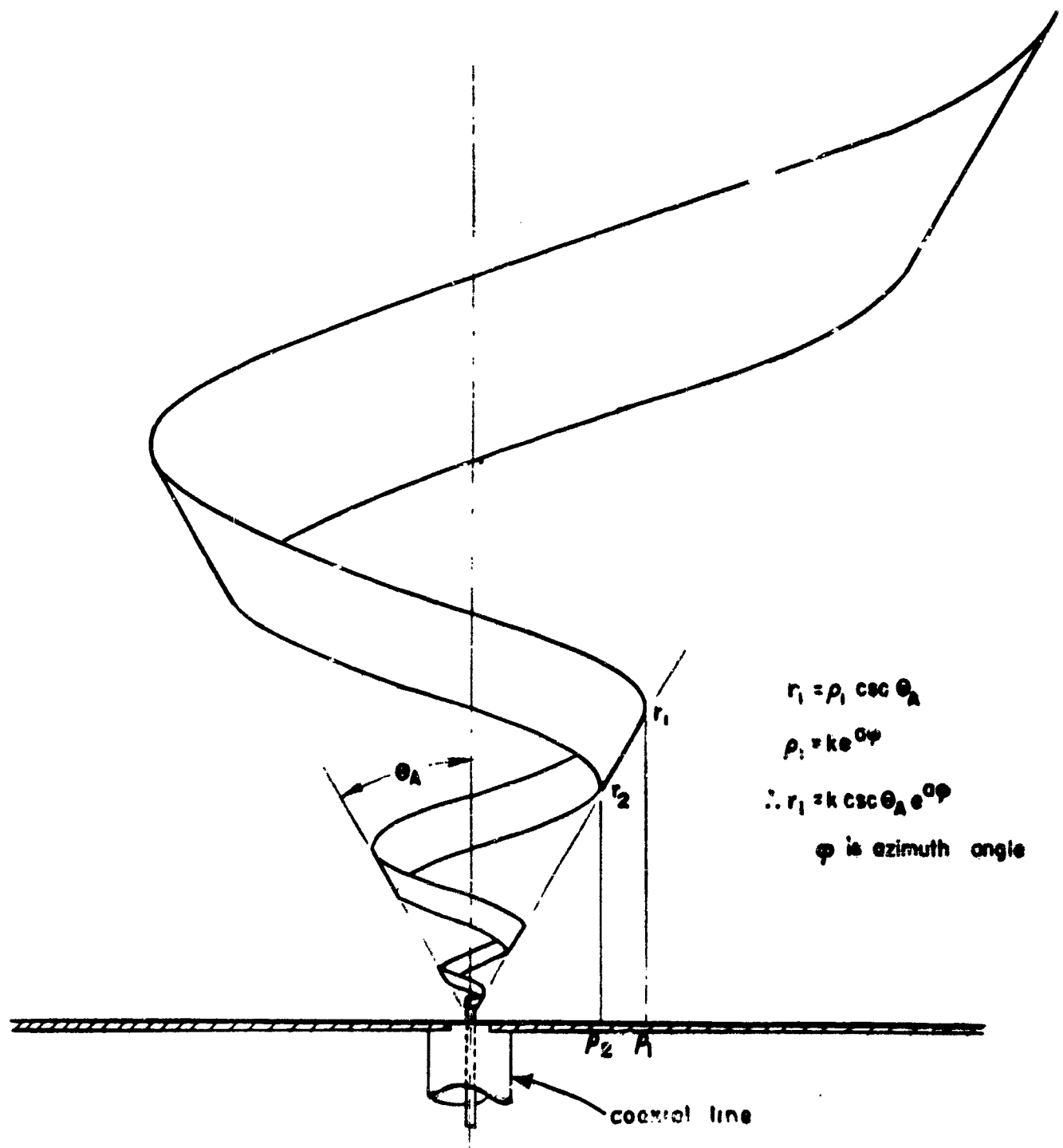


Figure 1 Conical Equiangular Spiral Antenna

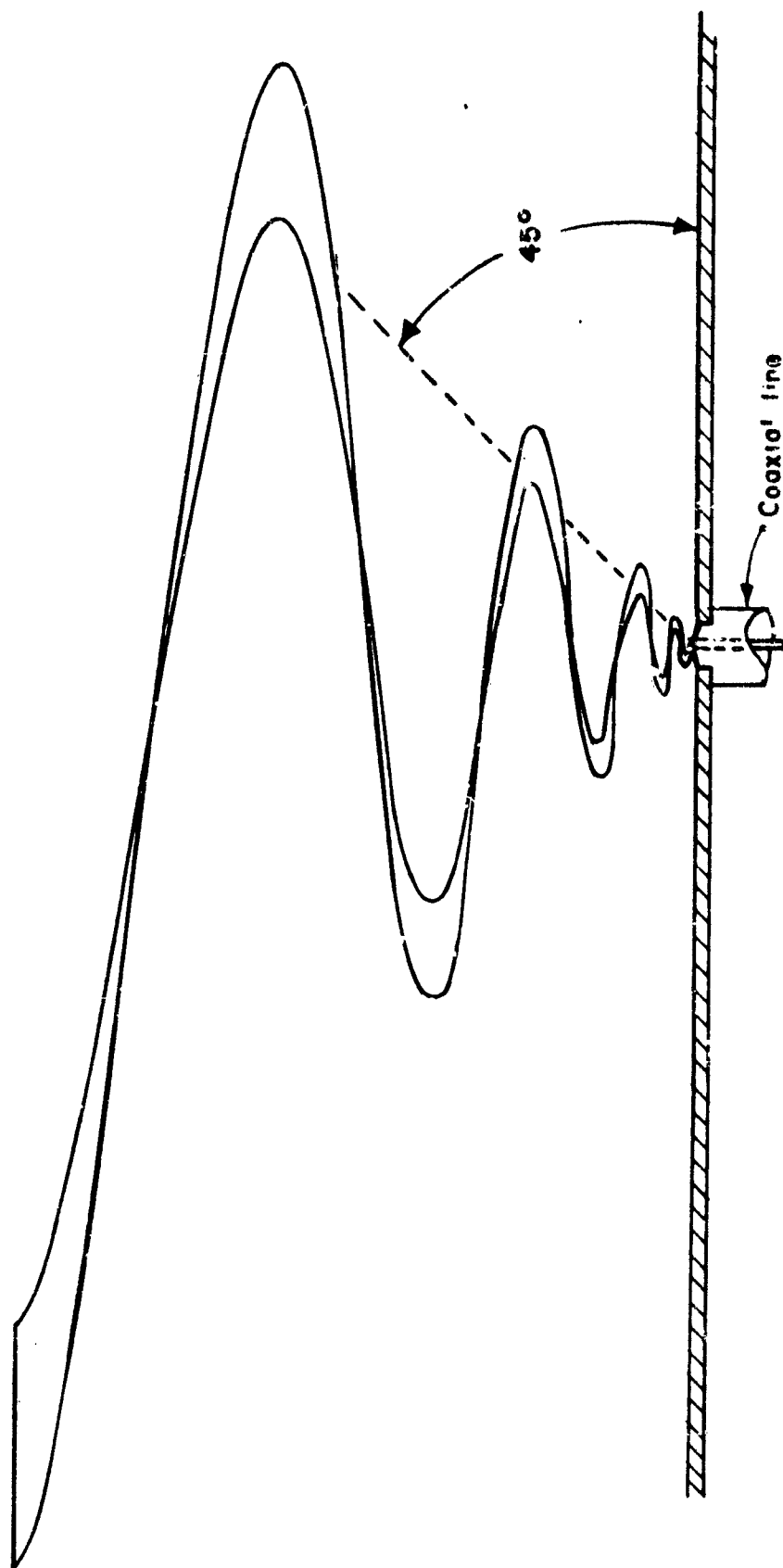


Figure 2 The Expanded Conical Equiangular Spiral

from an unbalanced line. In addition, this spiral is comparatively easier to fabricate than the expanded spiral.

### 2.2.1 The Design Parameters

Figure 1 shows the development of the conical spiral parameters, starting from the basic equation of the equiangular spiral in the  $\rho, \phi$  plane, which is  $\rho = Ke^{a\phi}$  where  $K$  and  $a$  are constants. Note that the surface of a cone may be developed on a plane, as shown in Fig. 3. As will be seen later,  $\alpha$  and  $\phi$  are the defining angles of the developed and projected spirals respectively.

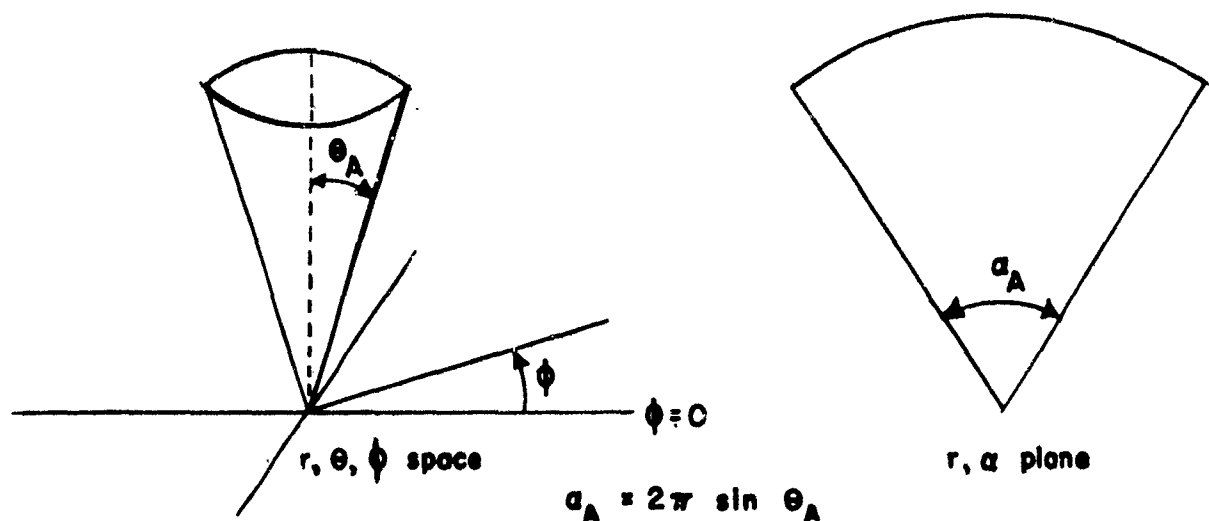


Figure 3 Development of a Spiral on a Plane

As  $\alpha$  turns through  $2\pi \sin \theta_A$  radians,  $\phi$  turns through  $2\pi$  radians. Expressed as a ratio

$$\frac{\alpha}{\phi} = \frac{2\pi \sin \theta_A}{2\pi}$$

or,

$$\phi = \alpha \csc \theta_A$$

This is the desired relation which allows us to cut the spiral from a plane sheet. Since there is a one to one correspondence between radial lengths on the cone (e.g.,  $r_1$  and  $r_2$  of Fig. 1) and radial lengths in the  $r, \alpha$  plane,

we may write

$$r = K \csc \theta_A e^{a \csc \theta_A \alpha}$$

where  $r$  is the radial coordinate in the  $r, \alpha$  plane.

Since  $\theta_A$  is constant,

$$a \csc \theta_A = a'$$

$$K \csc \theta_A = K'$$

therefore

$$r = K' e^{a' \alpha}$$

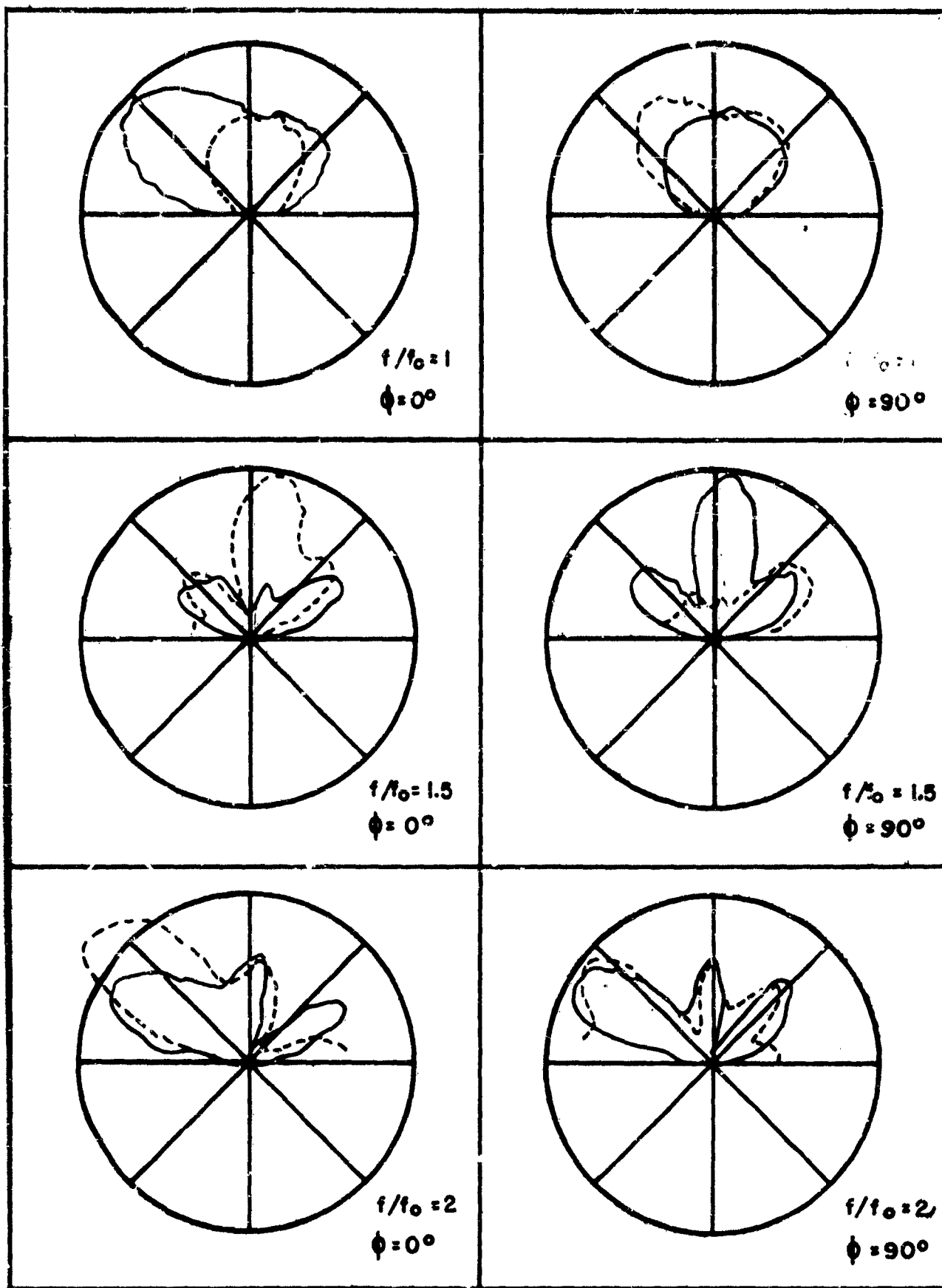
which is the equation of an equiangular spiral in the  $r, \alpha$  plane.

We have four design parameters at our disposal: they are  $K$ ,  $a$ ,  $\theta_A$ , and  $n$ , where  $n$  is the number of turns of any finite antenna. After selecting an arbitrary  $\theta_A$ , the other design parameters may be chosen by stipulating a conical spiral of  $n$  turns whose projection on the ground plane will reach a radius  $\rho_m$  in those  $n$  turns, starting with  $\rho_0 = K$ . ( $\rho_0$  is the value of  $\rho = Ke^{a\varphi}$  when  $\varphi = 0$ ). Another way of choosing the design parameters will be presented later.

### 2.2.2 The Radiation Pattern

To date, 21 different conical spirals have been built and their radiation patterns have been recorded on the 12' x 12' ground screen pattern recording facility at the University of Illinois.

The first six antennas were designed with small apex angles of  $22\frac{1}{2}^\circ$ ,  $30^\circ$ , and  $37\frac{1}{2}^\circ$ ; and had seven or eight turns. These antennas exhibited poor directional characteristics, as shown in Fig. 4. The next antennas built were of larger  $\theta_A$  of  $60^\circ$  and  $75^\circ$ , and of fewer turns (one to four). It was observed that the larger apex angle tended to produce a single-lobed radiation pattern. Typical patterns are shown in Fig. 5.



An 8-Turn Spiral-- $\theta_A = 30^\circ$   
 -----  $E_\theta$  Polarization  
 \_\_\_\_\_  $E_\phi$  Polarization  
 $f_0 = 1000$  mc.

Figure 4 Radiation Patterns: Principal Plane Patterns for Various Frequencies

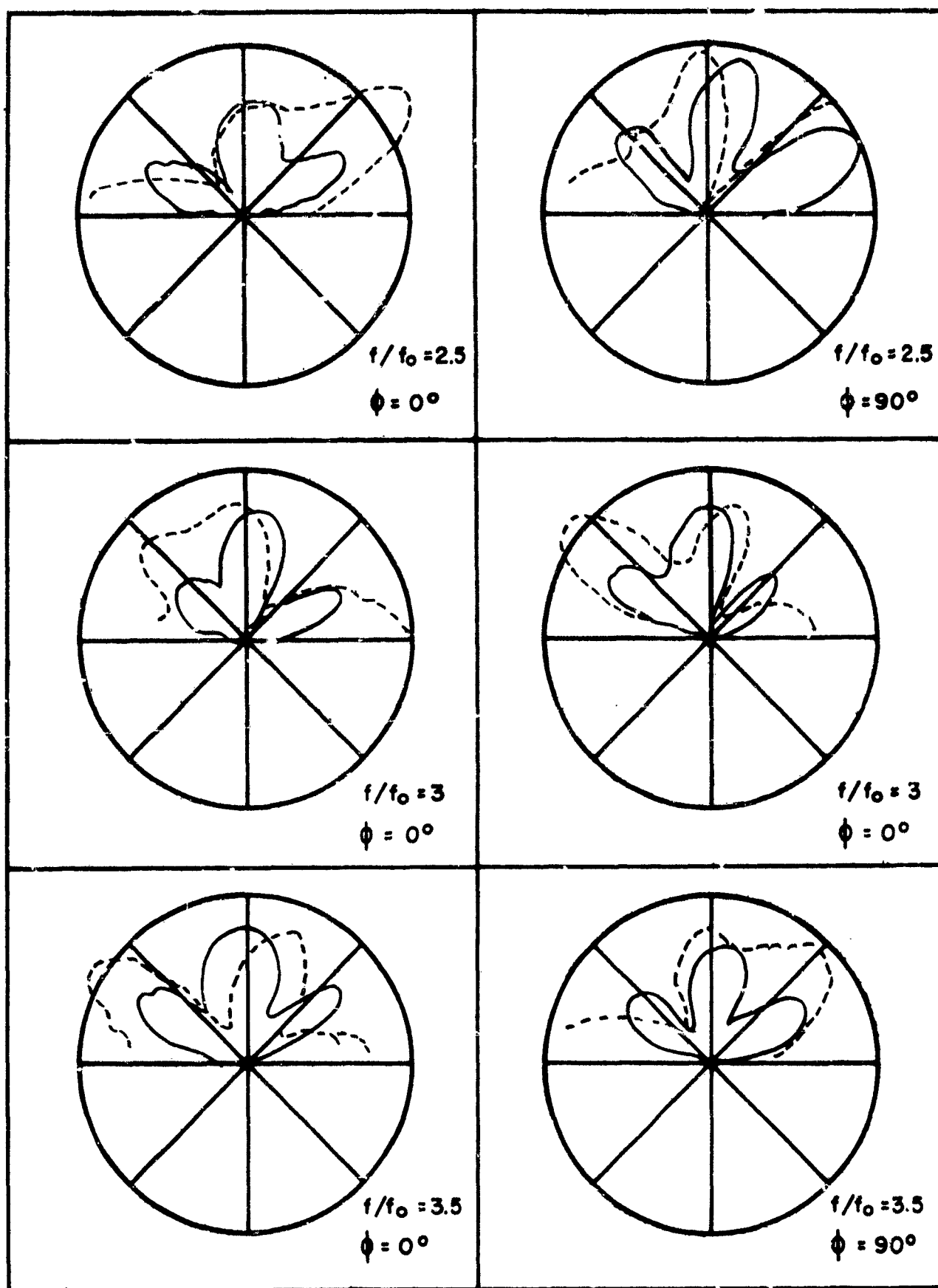


Figure 4 (continued)

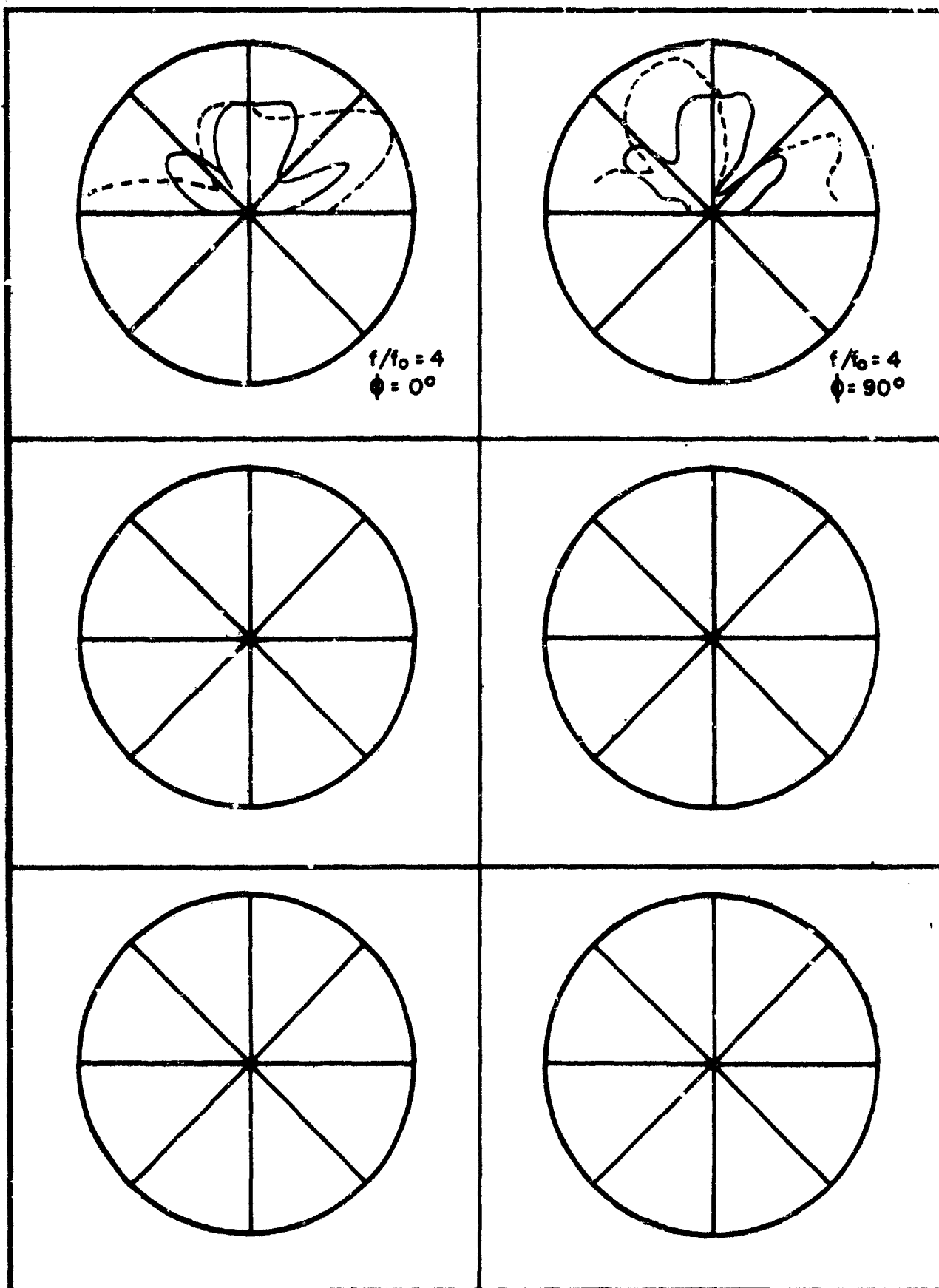
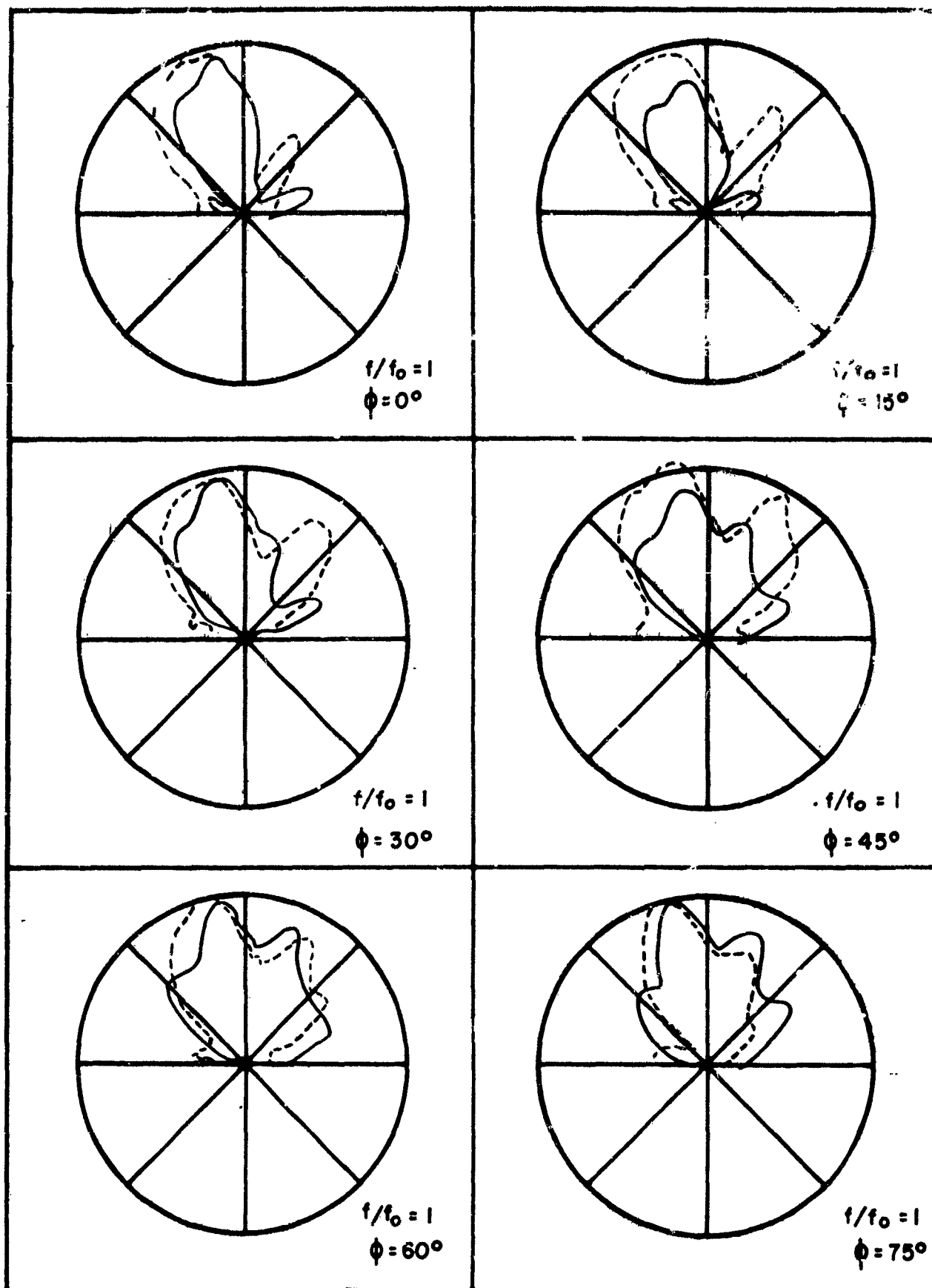


Figure 4 (continued)



A 3-Turn Spiral- $\theta_A = 60^\circ$

Figure 5 Radiation Patterns: Fixed Frequency Cuts in 15° Increments



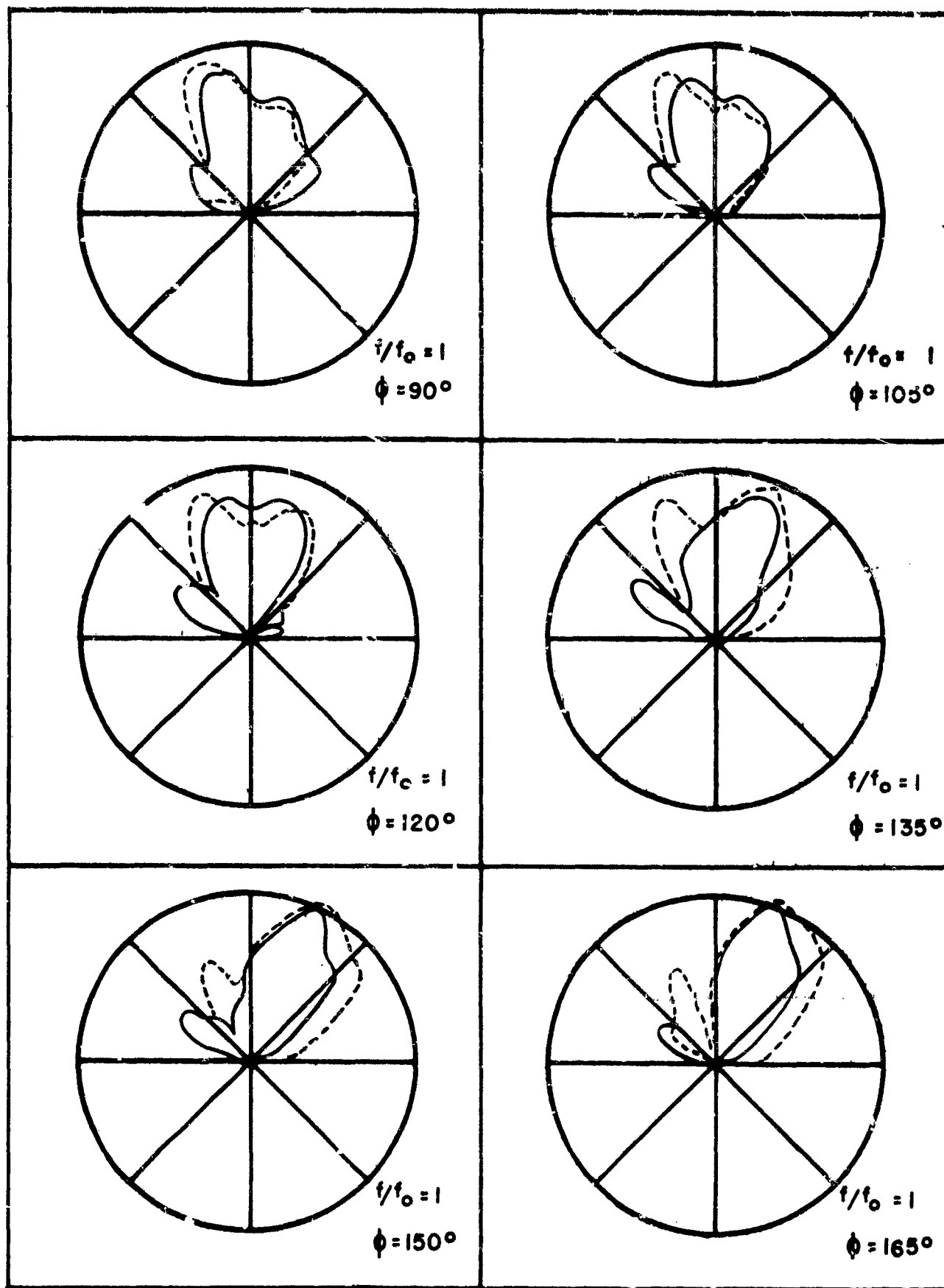
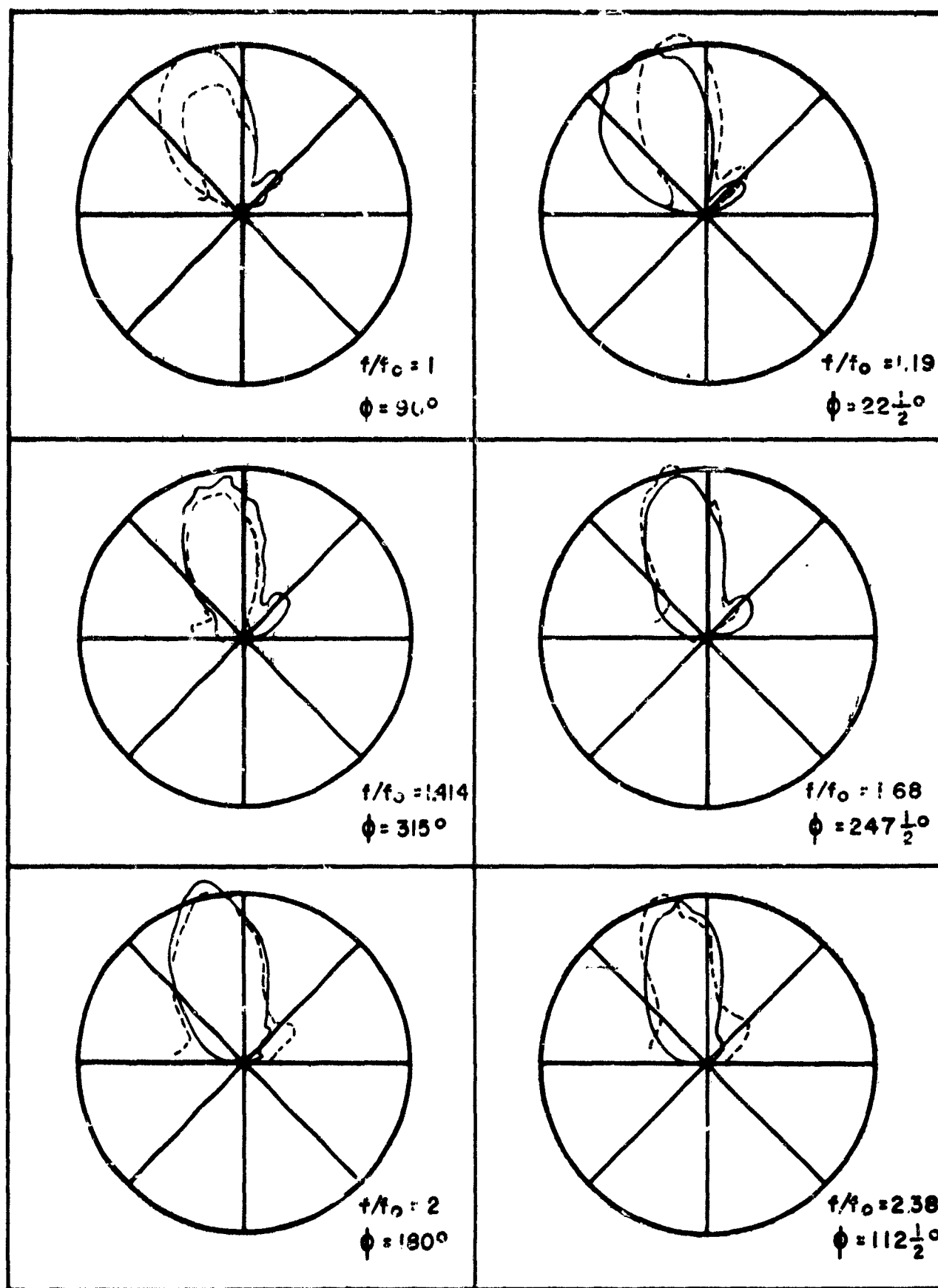


Figure 5 (continued)

The principle radiated lobe of all antennas exhibited a definite tilt away from the axis of the antenna. Furthermore, this tilted beam was found to rotate about the axis of the antenna at a constant tilt angle as the frequency was changed. This rotation was predicted by the "angular concept" of frequency independent antenna theory.<sup>1</sup> Upon further investigation it was found that the rotation of the pattern is proportional to the logarithmic increment of frequency, and that the proportionality factor is the spiral constant,  $a$ .

$$\Delta \varphi = 1/a \log \left( \frac{f_0 + \Delta f}{f_0} \right).$$

Using this expression, patterns were recorded such that the plane of the pattern was always through the principle beam maximum. To do so, a specific change in frequency was always accompanied by a corresponding rotation of the antenna. It was found that all of the antennas of large apex angles exhibited radiation patterns which, aside from the above mentioned rotation, were nearly constant with frequency over a wide band. Examples of such patterns are shown in Figs. 6 and 7. The initial radius and the final radius,  $\rho_0$  and  $\rho_m$ , respectively, are the same for both of these antennas. They differ in the number of turns, which is determined from the parameter " $a$ ". The effective measured bandwidth for these particular antennas is much less than was expected, for two reasons. First, the low frequency limit is always related to the finite size of the antenna. Second, the high frequency limit is necessarily restricted by the finite size of the feed section. However, in this particular measurement the recorded data at the higher frequencies was very inaccurate because the error in the alignment and positioning of the antenna became appreciable compared to the wavelength.



A 3-Turn Spiral- $\theta_A=60^\circ$

$a=0.147!$

----- $E_\theta$  Polarization

——— $E_\phi$  Polarization

$f_0=1000$  mc

Figure 6 Radiation Patterns: Pattern Rotation vs. Frequency

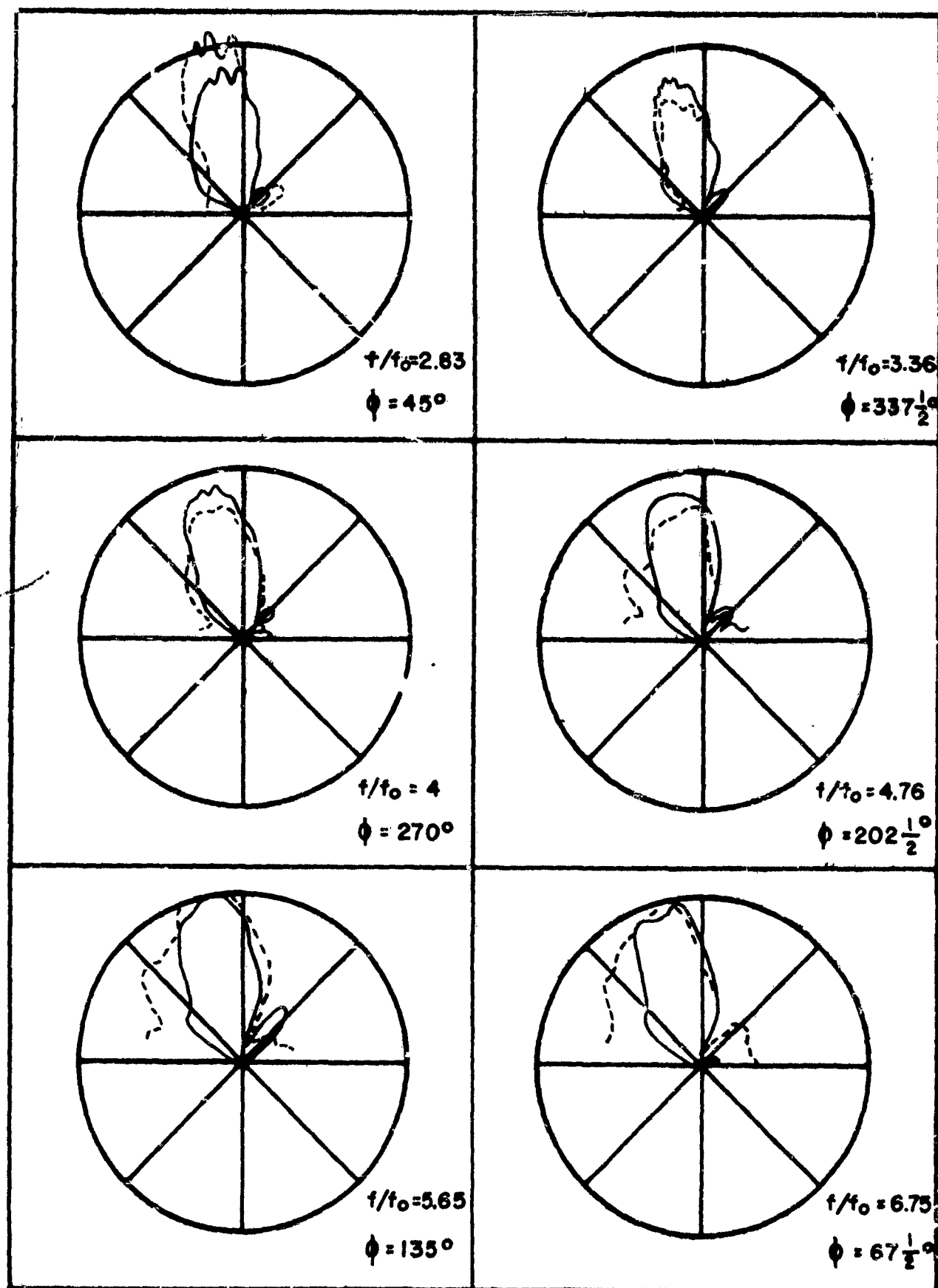
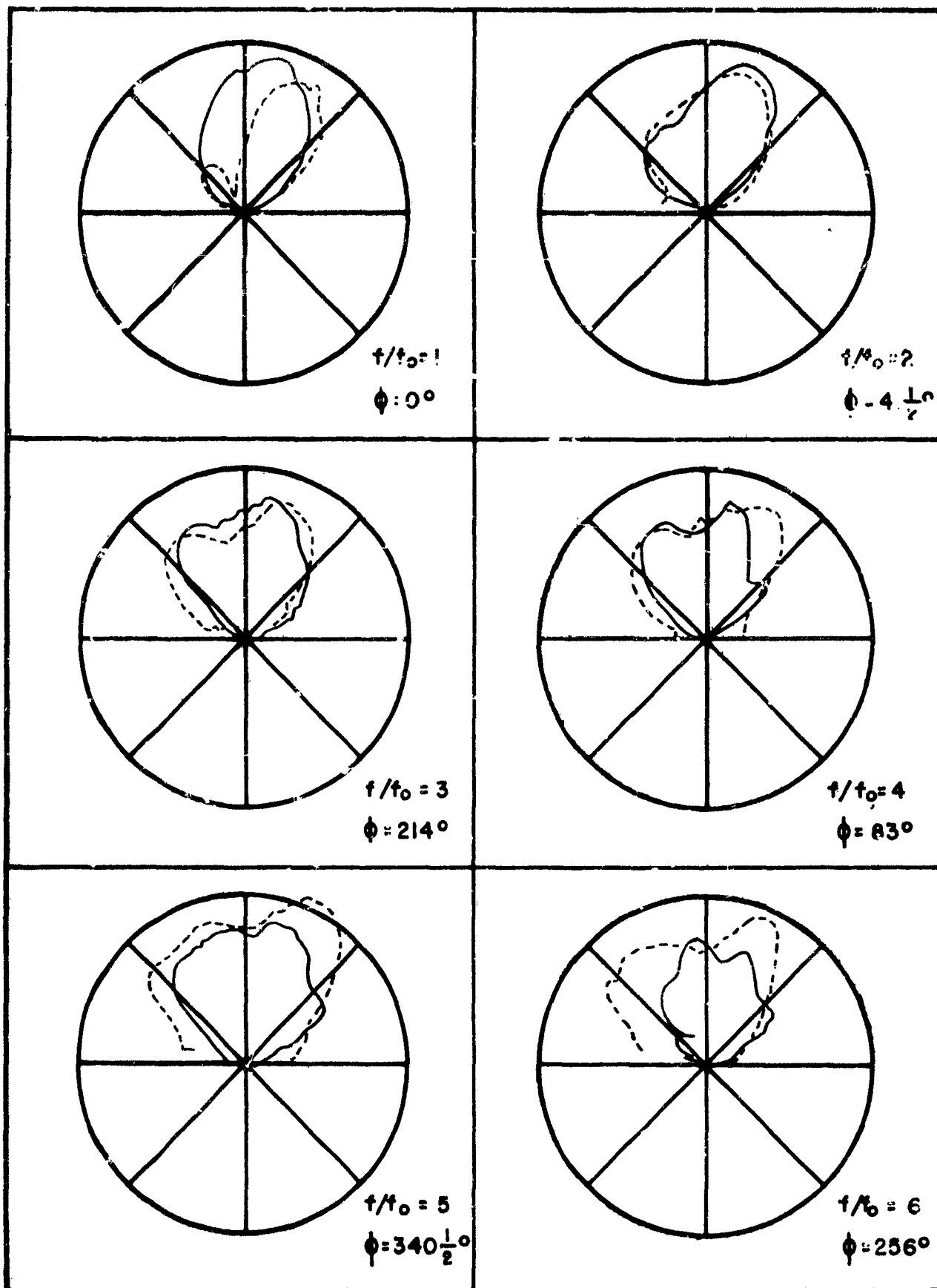


Figure 6 (continued)



A 5-Turn Spiral- $\theta_A=60^\circ$

$a=0.1245$

----- $E_\theta$  Polarization

\_\_\_\_\_  $E_\phi$  Polarization

$f_0=1000$  mc.

Figure 7 Radiation Patterns: Pattern Rotation vs. Frequency

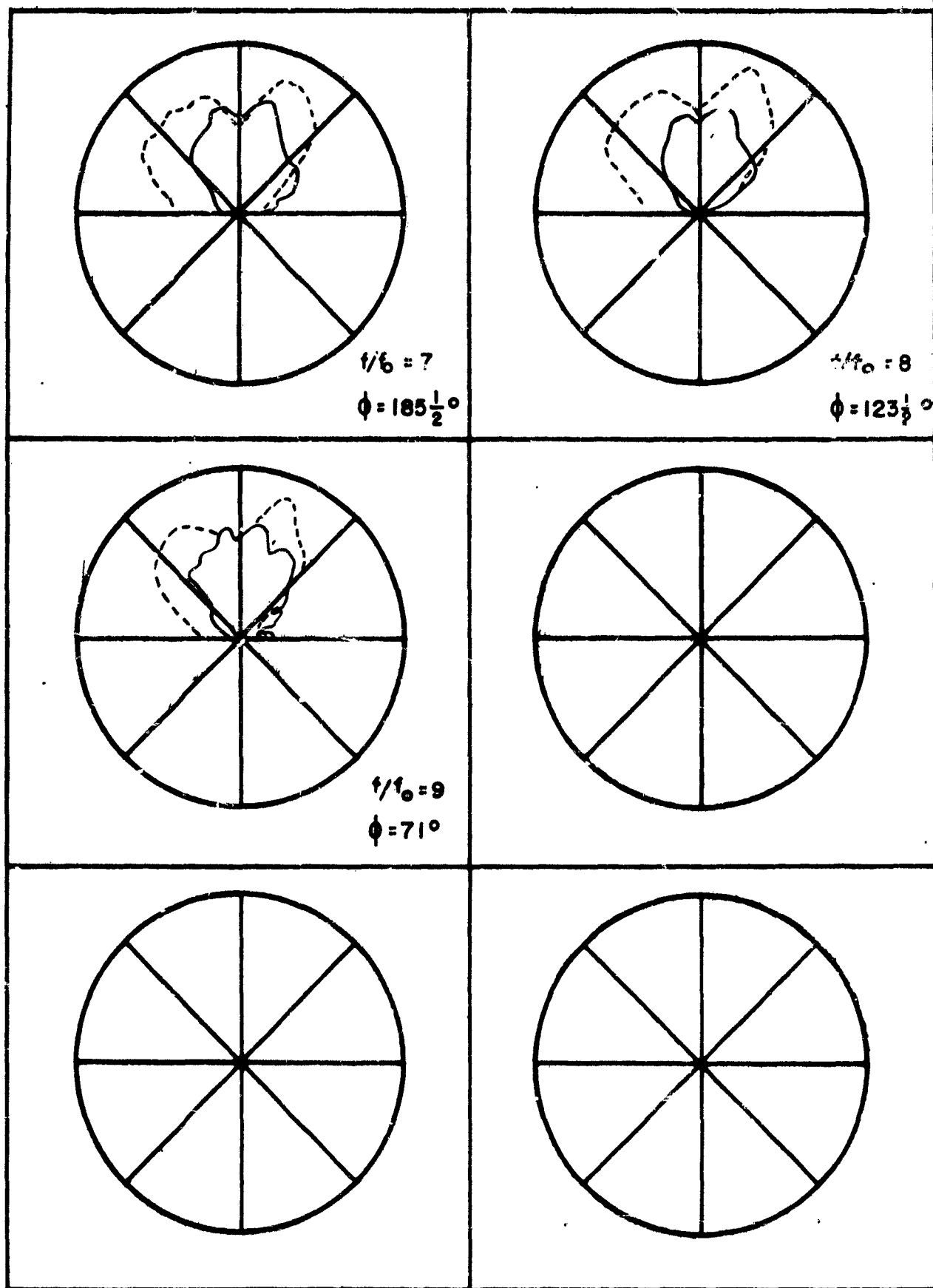


Figure 7 (continued)

Having shown that the rotation with frequency can be predicted, we may now design an antenna whose pattern will rotate through any prescribed angle with a specified percent change in frequency. A graph of pattern revolution versus frequency ratio and the parameter "a" is shown in Fig. 10. Several antennas were designed from this viewpoint, and the results were quite satisfactory in so far as rotation was concerned. However, the patterns themselves were still highly specialized and this would limit the practical utility of these antennas.

#### 2.2.3 Current Distribution

The amplitude of the current density distribution as a function of distance along the center of the arm of the antenna was measured over a band of frequencies. It was found that the current distribution changes from a slowly attenuated standing wave when the antenna is electrically short to a progressively more rapidly attenuated traveling wave, as the electrical length of the antenna is increased. It was found that the developed length of the arm of the antenna must be greater than approximately two wavelengths before this principle mode of operation is realized. This is shown in Fig. 11.

#### 2.2.4 Impedance Measurements

Results of a measurement of the input impedance of a conical spiral were rather inconclusive as concerns the magnitude of the impedance. However, the measurements indicated that this antenna behaves like a true frequency independent antenna. That is, the input impedance tends to remain constant above a certain frequency, determined by the physical length of the antenna. Furthermore, this so-called "cut-off" frequency is the same as that determined by the measurement of the current amplitude distribution as outlined in Section 2.2.3.

## 2.3 The Double Conical Spiral

A few double conical spiral antennas were investigated in addition to the above mentioned single spirals. The double conical spiral consists of two identical single conical spirals spaced  $180^\circ$  apart on a cone.

### 2.3.1 The Unbalanced Double Conical Spiral

In the unbalanced double conical spiral, the two arms of the antenna are electrically connected at the apex and fed over a ground plane from a coaxial line. The radiation pattern exhibited an on-axis null due to symmetrically opposed currents being out of phase and cancelling each other on the axis. The patterns were specialized, but the rotation took place as was expected. Typical patterns are shown in Fig. 8.

### 2.3.2 The Balanced Double Conical Spiral

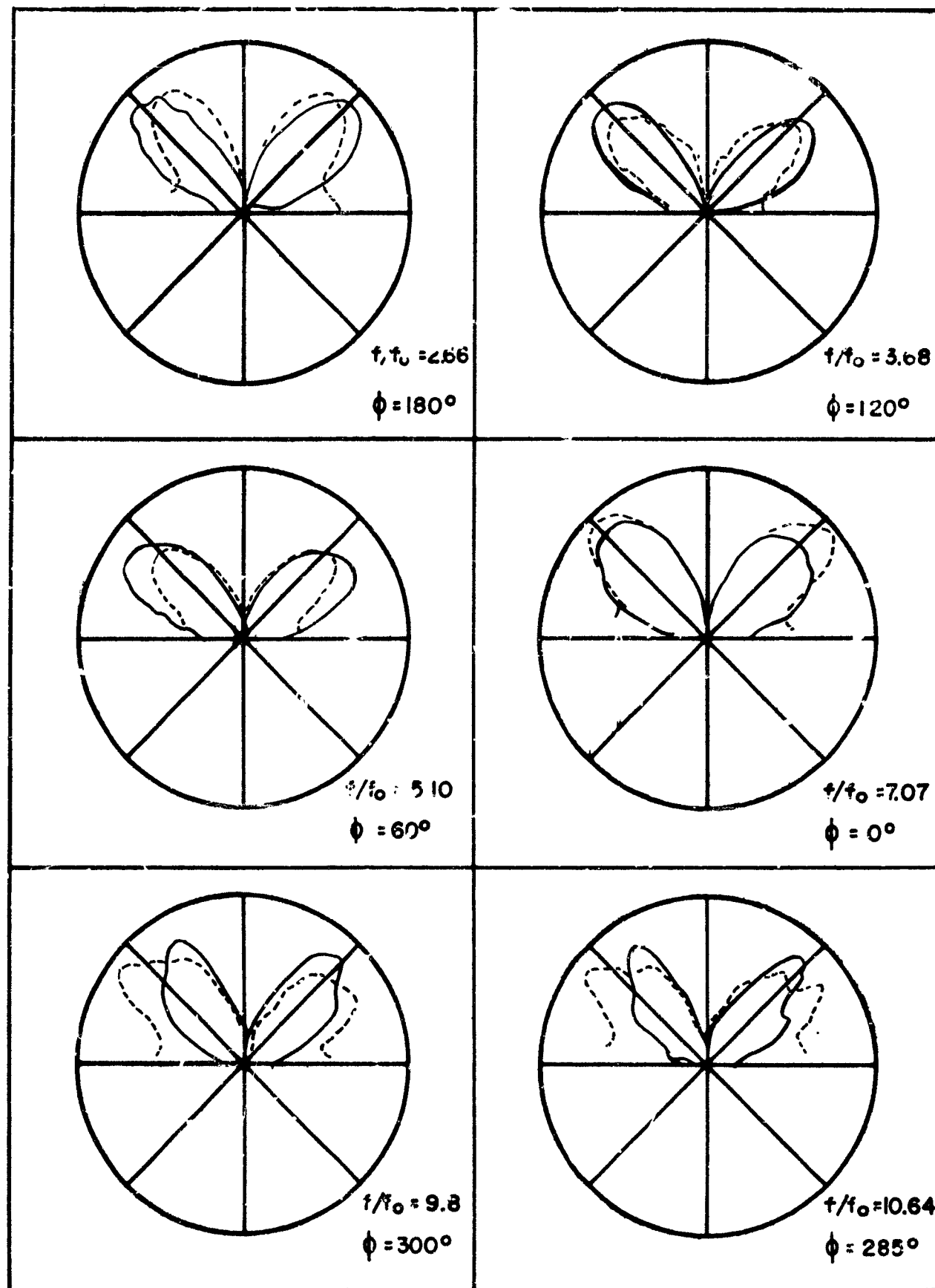
In the balanced double conical spiral, the two arms of the antenna are not connected, they are fed from a balanced line. Pattern measurements were somewhat limited due to the insertion of a balun, which was needed to obtain the balanced feed. This particular balun was rather narrow band; thus it tended to mask the performance of the antenna. However, results of pattern measurements over a relatively narrow band revealed that the patterns were symmetrical about the axis and that the principle beam maximum was pointed along the axis. Symmetrically located side lobes were predominant, and in some patterns their amplitude was greater than that of the on-axis beam. Typical patterns are shown in Fig. 9.

An attempt at determining the pattern rotation led to inconclusive results, because the measurement had to be confined to a narrow band. However, there is no reason to believe that pattern rotation does not take place.

## 3. CONCLUSION

It can be said that no effective means of controlling the directive radiation of the conical spiral has been achieved, even though the pattern rotation can be





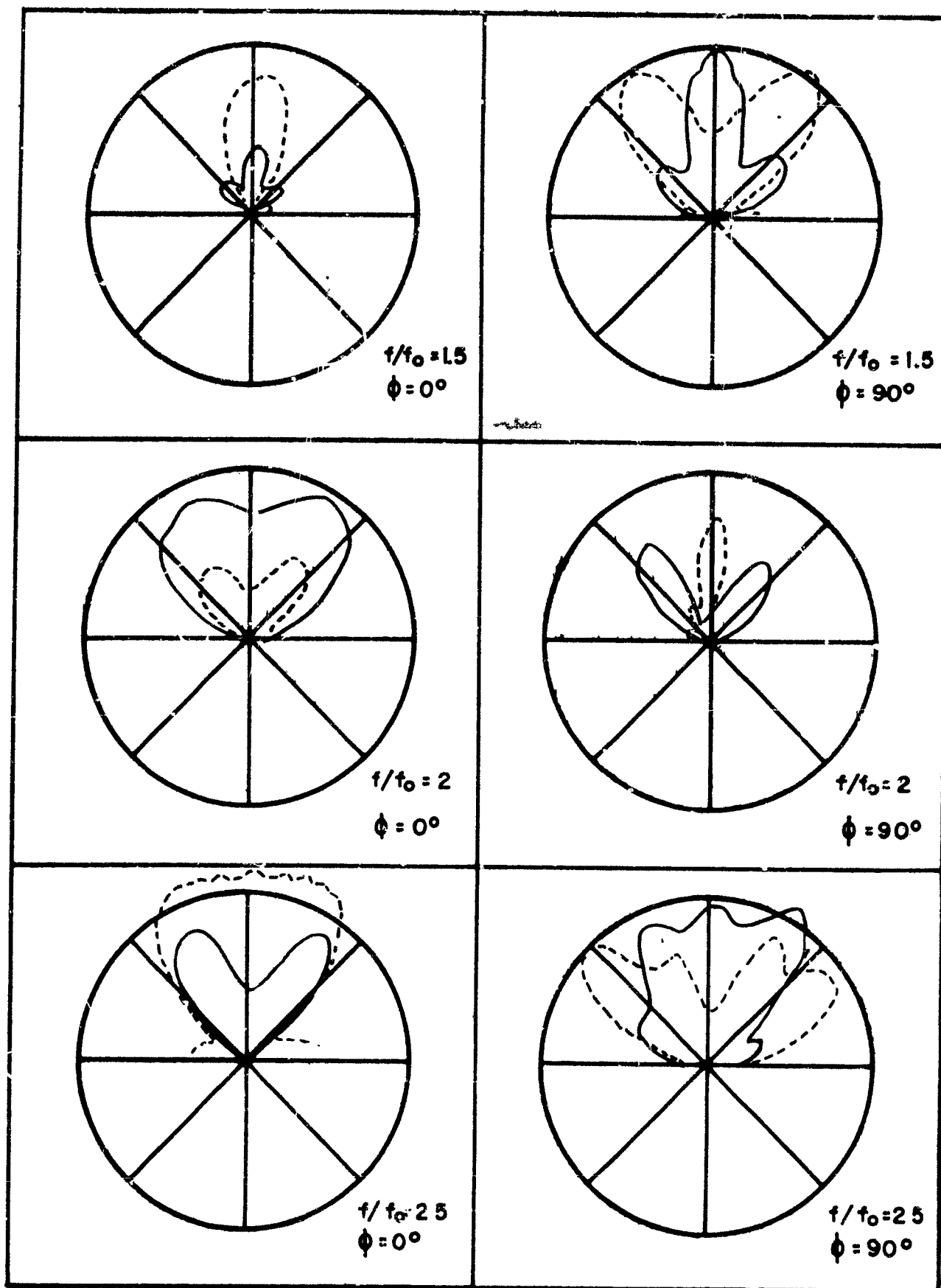
A 2-Turn Unbalanced Double Spiral-- $\theta_s=75^\circ$

----- $E_\theta$  Polarization

——— $E_\phi$  Polarization

$f_0=1000$  mc.

Figure 8 Radiation Patterns: Pattern Rotation vs. Frequency



A 2-Turn Balanced Double Spiral-- $\theta_A = 75^\circ$

----- $E_\theta$  Polarization

——— $E_\phi$  Polarization

$f_0 = 1000$  mc.

Figure 9 Radiation Patterns: Principal Plane Patterns for Various Frequencies

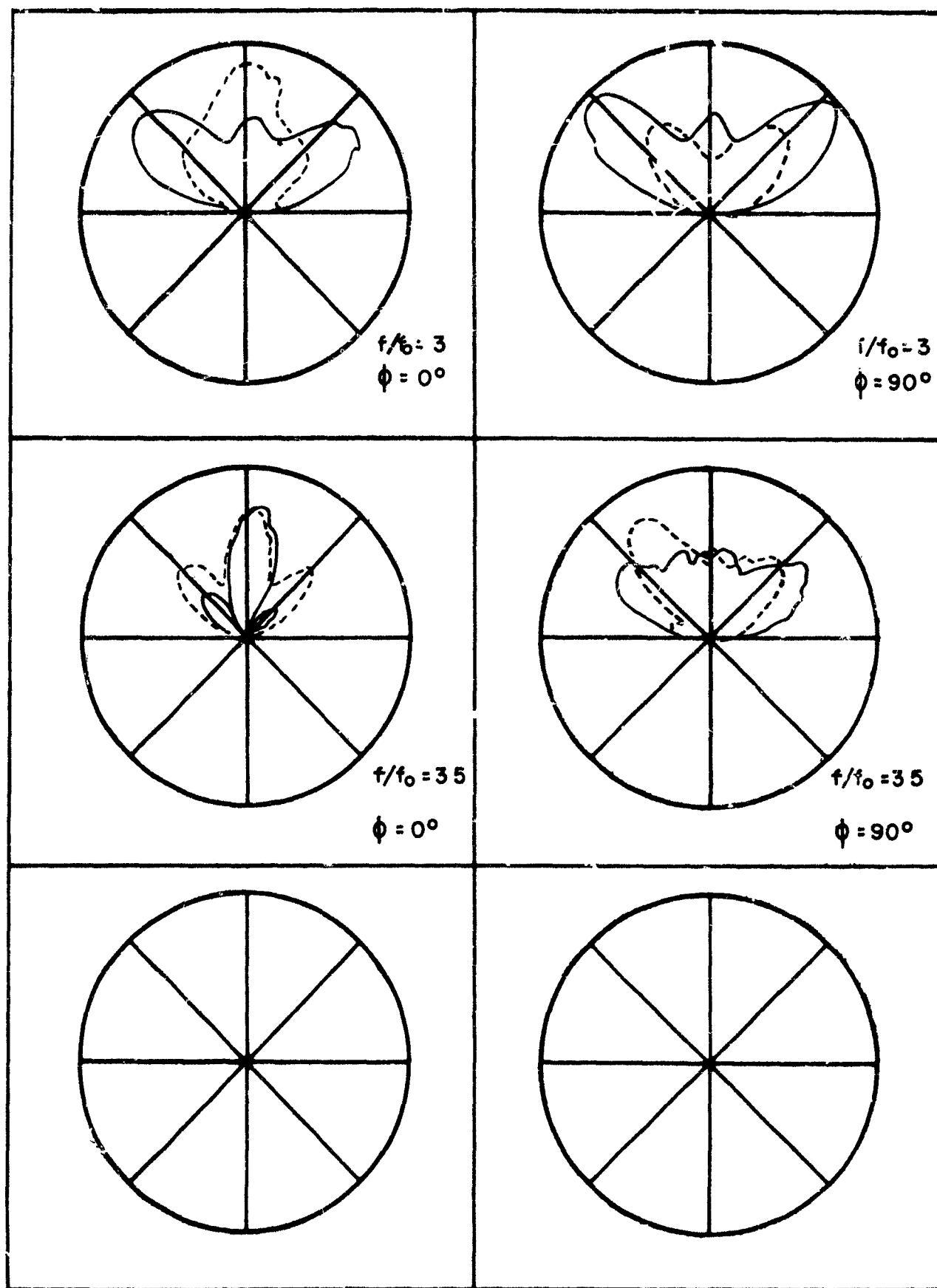


Figure 9 (continued)

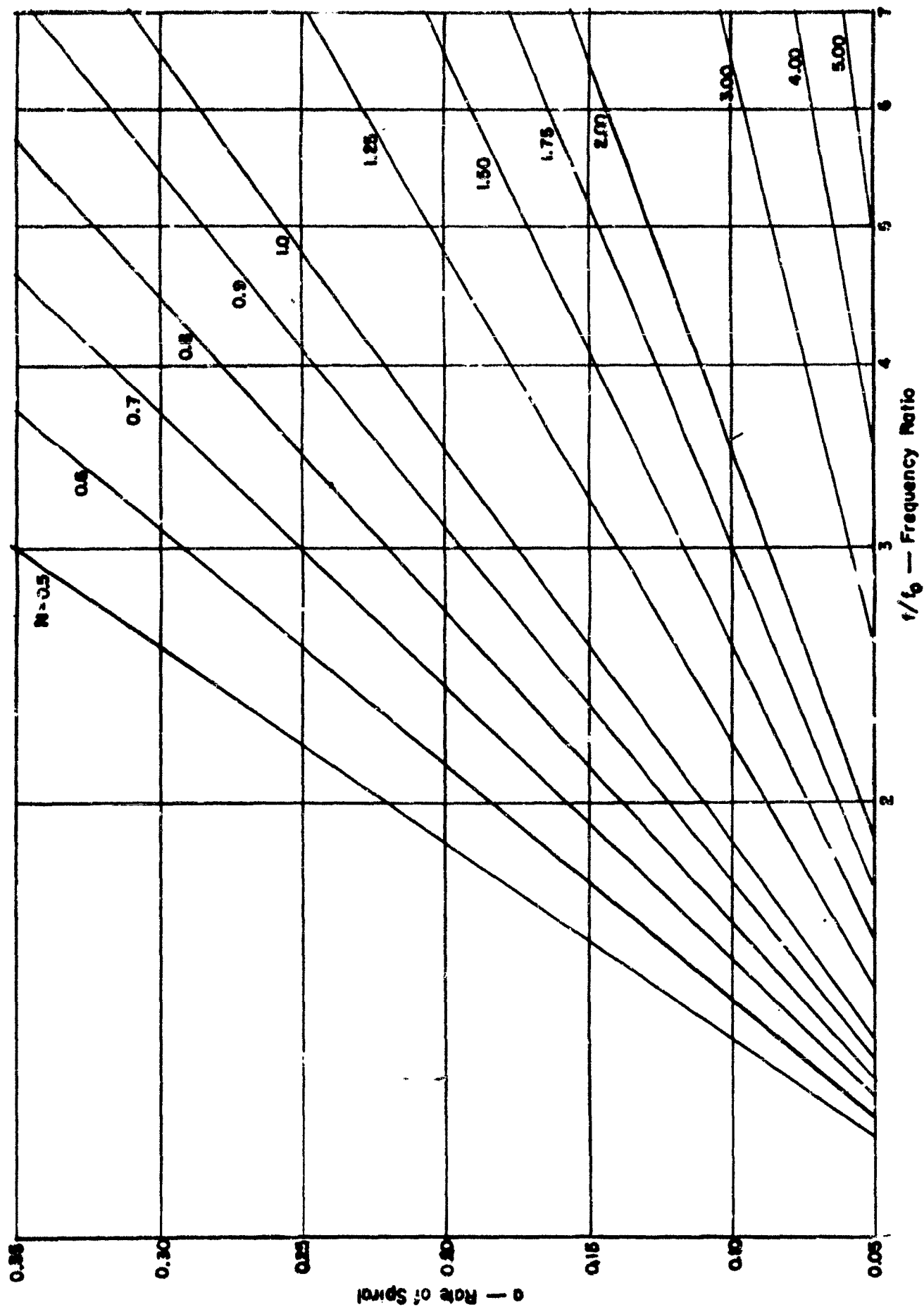
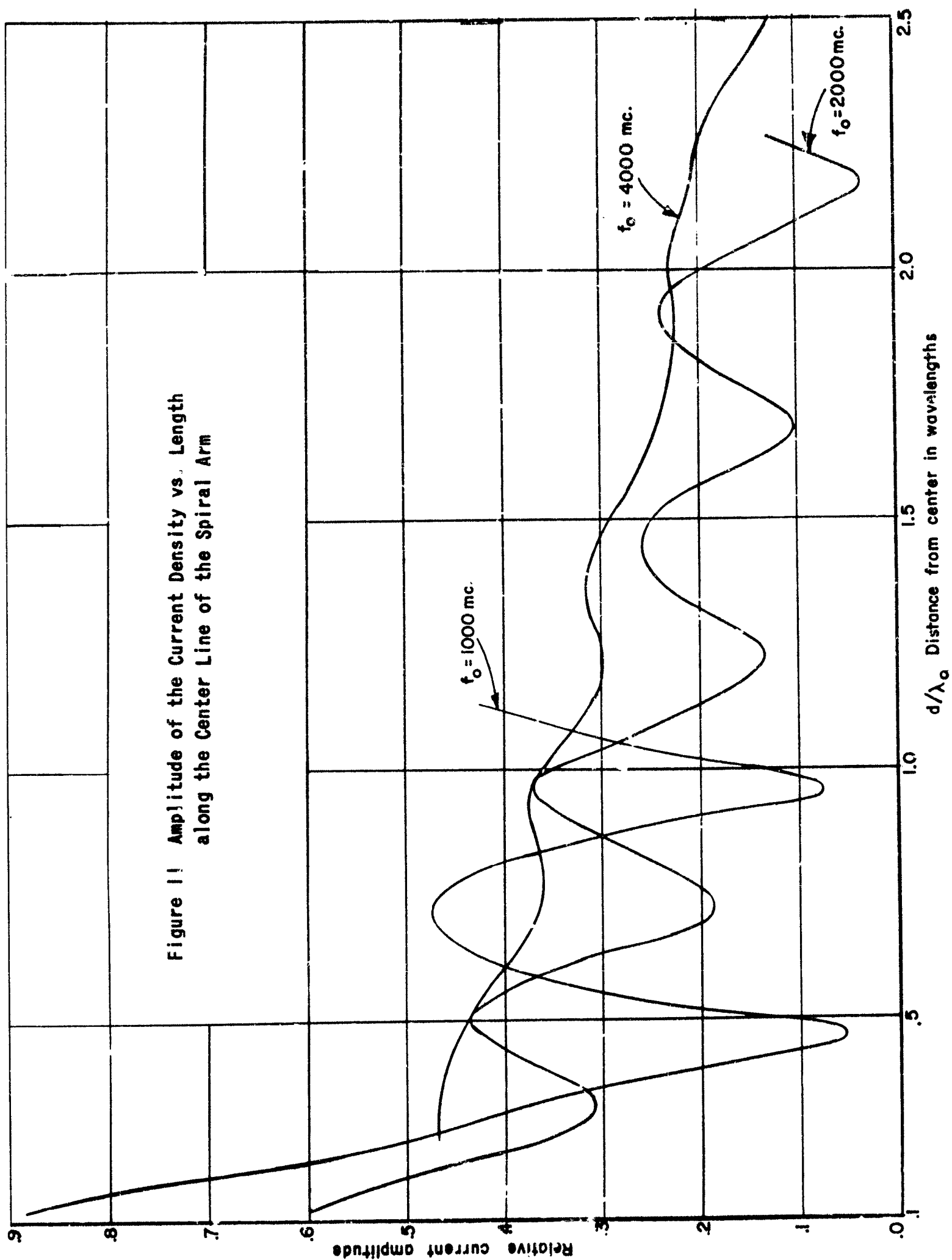


Figure 10 Pattern Revolution versus Frequency Ratio and Rate of Spiral ( $N$  = Number of Revolutions of the Pattern)

Figure 11 Amplitude of the Current Density vs. Length  
along the Center Line of the Spiral Arm



predicted with a high degree of accuracy. This is not to imply that nothing can be done to control the directive radiation; it is to say that the factors which do control the radiation have not been determined, since only a few members of a large set of possible variations of the design parameters have been investigated. However, the author feels that continued investigation of this antenna would bear only redundant information until the exact theory of antennas of this type is more clearly understood.

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